in good condition and doing well; the prospects were for about a half crop of apples, but were not very encouraging for cherries, peaches, pears, and plums.—*E. C. Vose.*

Wisconsin.—The weather was characterized by an excess of precipitation, especially in the southern and central counties, and a deficiency of temperature and sunshine. The continued wet weather retarded corn planting, but was generally favorable to the growth of grass and grain crops. Frosts, more or less severe, occurred in the central and northern counties, and light snow was recorded on the 8th and 9th, but no material damage resulted.—*W. M. Wilson.*

Wyoming.—The month was unusually cool, the mean temperature for the first half of the month averaging about 6° per day below the normal. The precipitation was heavy and well distributed. At the close of the month, ranges were in excellent condition, and meadows gave promise of a large crop of native hay. The cool, wet weather delayed seeding and at the close of the month, gardens, grain, and alfalfa, while looking well, were much later than usual.—*W. S. Palmer.*

SPECIAL ARTICLES.

STUDIES ON THE DIURNAL PERIODS IN THE LOWER STRATA OF THE ATMOSPHERE.

By Prof. FRANK H. BIGELOW.

IV.—THE DIURNAL PERIODS OF THE TERRESTRIAL MAGNETIC FIELD AND THE APERIODIC DISTURBANCES.

THE DIURNAL VARIATIONS OF THE TERRESTRIAL MAGNETIC FIELD.

In the years 1889–1891 I computed a series of hourly magnetic deflecting vectors for 30 stations, in polar coordinates, $s =$ total vector, $\sigma =$ the horizontal component, $\alpha =$ the angular altitude positive above the horizon, $\beta =$ azimuthal angle counted from the north point of the magnetic meridian through the west $= 90°$, south $= 180°$, east $= 270°$. These were derived from the rectangular variations, ΔH horizontal force positive northward, ΔD declination positive westward, ΔV positive zenithward, by means of a simple scale diagram containing polar and rectangular coordinate systems at the same center. This presentation of the available data of observation included the diurnal variation of the magnetic field, and also the variation from day to day eliminating the hourly periodicity. The resulting tables are bulky and there has been no opportunity to publish them *in extenso*, but brief summaries of the subject matter have appeared in several places[1]. This work has aroused some critical discussion, but for the greater part of an academic character which threw little additional information upon the solution of the numerous difficult problems in solar physics and cosmical meteorology that are involved. It is quite evident that the authors of the comments did not always have in mind the details or the minor facts which must be accounted for in a final solution. It is easy to propose a vague general theory, but to bring it down to exact harmony with the many special peculiarities of the varying magnetic field is no easy problem to resolve.

In 1889 Schuster[2] published his solution for the diurnal variation of the *vertical* force derived from four stations, and ascribed to the assumed counterpart electric currents to a sensitive state of the *upper* atmosphere. In 1897 von Bezold[3] further discussed the subject as a continuation of the same data. In 1902 H. Fritsche[4] computed the variations from the difference data, ΔH, ΔD, ΔV, by means of Gaussian coefficients, and likewise attributed the magnetic effects to supposed electric currents in the upper atmosphere. In his paper of 1903, Adolph Schmidt[5] has adopted the method of deflecting vectors, and in his other papers seems to favor an electric current system in the high strata. Also, A. S. Steen[6] has worked out an elaborate system of upper air electric currents to account for the diurnal variation of the magnetic field.

Other writers, W. Sutherland, A. Nippoldt, W. van Bemmelen, J. Liznar, Carlheim-Gyllensköld, Ch. Chree, and L. A. Bauer seem to favor a solution of the same character.

I must confess that, aside from the entirely vague nature of this hypothesis, I have never been able to concede that it contains the true germ of the solution of the problem. That theory has received much additional popularity from the supposed bombardment of the upper strata of the earth's atmosphere by the ions ejected from the solar surface and transported to the region of the earth's orbit by the mechanical pressure of light, which were described as thereupon inducing the required electric currents. It was quite impossible to understand how such a general action of currents in the upper strata could produce the strongly localized effects observed at the surface of the earth, which so persistently follow the meteorological elements both diurnally and annually. I have, accordingly, (1) argued against the efficiency of these hypothetical upper strata electric currents to produce the details noted in the magnetic field, and I have (2) endeavored to show that the general motions of the atmosphere and the cyclonic and anticyclonic actions can not account for the observed phenomena, taken the world over, as shown by my 30-inch globe, model of 1893.

It is true that my own working hypothesis was not complete even in my own mind, and I have supposed there are steps in the series of causes and effects that still require to be added. My view was simply this, that the sun's electromagnetic or radiant field of energy falling upon the atomic and molecular constituents of the earth's atmosphere transformed them into temporary magnetic states, by polarizing some of them *in situ*, that is, throughout the strata traversed by the solar energy. These temporary magnets produced a quasi magnetic field which deflected the normal field as observed. The deflecting forces were the products of the physical processes involved in this action of the radiation upon the atoms and molecules of the atmosphere. This theory was constructed before the phenomenon of ionization of the constituents of the terrestrial atmosphere by solar radiation had been discovered, and, of course, there was little scientific material to justify my hypothesis at that time. Furthermore, after the discovery of the existence of positive (+) ions and negative (—) ions as constituents of the atmosphere had been made, it still remained impossible to match the computed magnetic deflecting forces with the pressure and temperature period of diurnal variation as observed at the *surface* of the earth. The search for conclusive evidence of the synchronism of magnetic vectors and surface temperatures and pressures was always unsuccessful, but, fortunately, this defect now seems to have been overcome by the results of the computations summarized in this present series of papers upon diurnal pressure and temperature waves in the free air above the surface within one mile of the ground. The desired synchronism seems to be so perfect as to leave little ground for further doubt that the diurnal variation of the earth's magnetic field is due to the movement of the positive (+) ions of electricity in the lower strata of the atmosphere in streams that are induced and controlled chiefly by the diurnal temperature waves that prevail in the lowest strata. I shall, accordingly, consider this paper as a supplement to chapter 4 of Bulletin No. 21. The description of the magnetic vectors there given is correct and in agreement with the systems derived by later computers, but the process of producing them, as now understood, is in accordance with the facts that have been worked out since that paper was written.

[1] Weather Bureau Bulletin No. 2, 1892. Astrophysical Journal, October, 1893. American Journal of Science, December, 1894, August, 1895. Weather Bureau Bulletin No. 21, 1898. Weather Bureau Annual Report, 1898–99, chapter 9. Eclipse Meteorology and Allied Problems, 1902, chapter 4.

[2] The Diurnal Variation of Terrestrial Magnetism. A. Schuster, 1889.

[3] Zur Theorie des Erdmagnetismus. W. von Bezold, 1897.

[4] Die Tägliche periode der Erdmagnetischen Elemente. H. Fritsche, 1902.

[5] Eine Sammlung der wichtigsten Ergebnisse erdmagnetischer Beobachtungen. A. Schmidt, 1903.

[6] The Diurnal Variation of Terrestrial Magnetism. A. S. Steen, 1904.

THE DIURNAL MAGNETIC VECTORS AS THE EFFECT OF THE DIURNAL TEMPERATURE WAVES UPON THE REDISTRIBUTION OF THE POSITIVE IONS IN THE LOWER STRATA OF THE ATMOSPHERE.

This subject can be best presented to the reader by making a compilation of the vectors of the diurnal deflecting magnetic forces and as computed for the same latitudes as those represented by the meteorological stations that have been used in the comparison. For this purpose the following five stations have been selected, as they are located in the North Temperate Zone, but in widely distributed longitudes: Washington, Paris, Vienna, Tiflis, and Zi-ka-wei. Properly, Zi-ka-wei belongs partly to the Temperate Zone belt and partly to the Tropic Zone belt, magnetically considered, because it is so far from the north magnetic pole as to be immersed in the tropical influence during several months. Although this affects the azimuth of the hours during the night, I have not removed it from the group of stations. The computed values of s, α, β are extracted from the tables described in chapter 4, of Bulletin No. 21, and an example is given in full for the months of February and August in Table 10, "Hourly values of the polar coordinates, s, α, β, at five stations in the North Temperate Zone". The mean values were computed for each element at every hour, and these are given for each month in Table 2, "Vectors of the diurnal magnetic deflecting forces". s is in units of the fifth decimal or 0.00001 of the unit of the C. G. S. system; $\alpha =$ the altitude angle positive above the horizon; $\beta =$ the azimuth angle counted from the north through the west.

It is difficult to exhibit the results of the Tables 10 and 11 on a diagram of only two dimensions, and I have made use in my studies of globe models constructed of rubber balls with pins for vectors, or else the large 30-inch globe model already mentioned. However, a drawing has been made in fig. 55, "Diurnal variation of the magnetic vectors s, α, β for latitudes $+30°$ to $+60°$". The vector length s and the vertical angle α are plotted for each month, and the direction in azimuth β is laid down only for January and July, as the variation in this element is not very great in the course of the year. We should, therefore, interpret the vectors as follows: The vector $(s\ \alpha)$ should be understood to stand in the plane of the azimuth β, and make with it the angle α which is here given. Generally, the vectors from 8 a. m. to 7 p. m. are directed toward the south, and those from 8 p. m. to 7 a. m. toward the north. As my purpose is to consider chiefly the relation of the streams of + ions in the air to the vector $(s\ \alpha)$ I have practically sacrificed the azimuth in the diagram. On the globe model the entire system is clearly displayed and it should be studied in that way.

On fig. 55 there are seen to be four critical points in the distribution of the diurnal vectors:

(1) The first point marks a sudden increase in the value of the deflecting force s up to a maximum, and it occurs in the forenoon, ranging from about 8 a. m. in winter to 6 a. m. in the summer. This is the hour at which the azimuth β shifts from the northern to the southern quadrants. About two hours later the vertical angle α passes through 0° so that the vector changes from below to above the horizon.

(2) The second point occurs at 11-12 a. m. in winter and 10-11 a. m. in summer, where the azimuth β shifts from east to west through the south, this being the well-known reversal of the needle before noon. The value of s at this point is at a slight minimum relative to its values earlier and later; this midday minimum appears in nearly every month of the computation, but especially in summer.

(3) The third point occurs after the true midday maximum of s, about 3 p. m., where the vector $(s\ \alpha)$ changes from above to below the horizon, and α passes again through the zero value of the angle. This point changes from about 2 p. m. in winter to 4 p. m. in summer, thus moving in the opposite direction from midday to that indicated in the forenoon vectors.

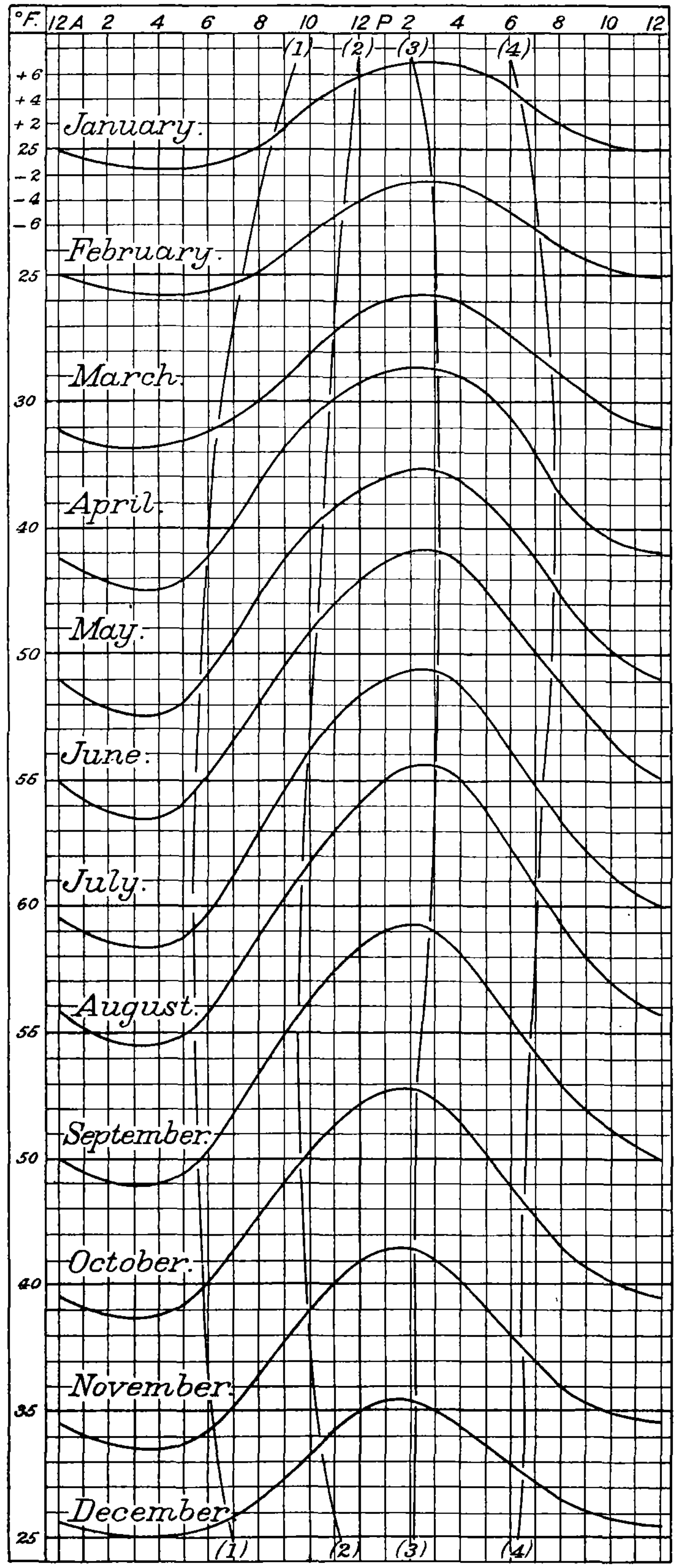


FIG. 56.—The annual variation of the surface temperature at Blue Hill.

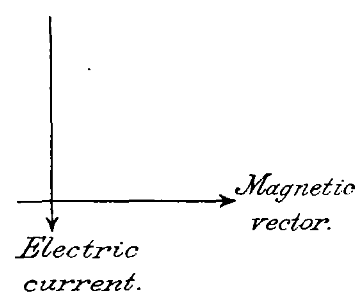
(4) The fourth point is where the azimuth β shifts from the first and second quadrants to the third and fourth, and it occurs at about 6-7 p. m. in winter, but at 7-8 p. m. in the summer, at the time of the setting of the sun. On fig. 55 these four special points in the system of diurnal vectors are indicated by the four lines marked (1), (2), (3), (4), and by

their course they show that the entire action which produces this magnetic disturbance of the normal field, contracts in time toward noon in the winter, and spreads away from it in the summer. This remarkable change in the location of the turning points is related without doubt to a similar change in the diurnal distribution of the temperature in the lower strata of the atmosphere, which must be closely associated with the magnetic variations.

In order to show how exactly these two phenomena synchronize in time during the course of the year, I have transferred to fig. 56 from figs. 14–25 the surface temperatures as observed at Blue Hill, plotting them in the sense indicated by the coordinate values. If the line (1) is drawn at the locus of the first active rise of temperature, at about two hours later than the minimum, the course is marked at an earlier hour in summer than in winter. The line (2) is drawn at about halfway up the forenoon temperature slope; line (3) at the maximum of the temperature, and line (4) at about halfway down the afternoon temperature slope. On comparing the lines (1), (2), (3), (4) of fig. 56 with those of fig. 55, it is observed that the annual curvature of the lines is generally so much in agreement as to make it very probable that the magnetic field and the temperature are both direct effects of the solar radiation, which itself has an entirely similar course to these in the North Temperate Zone. Now, since it is well known that this diurnal temperature effect is confined to the lower strata of the atmosphere, within two miles of the surface, I have been unable to concede that the diurnal magnetic variations can be caused by electric currents in the *upper* strata of the atmosphere, as assumed by Professor Schuster and other magneticians, or that it can be caused by a bombardment of the *upper* strata by the ions transported in the solar radiation, as supposed by Professor Arrhenius and other physicists. While I have been unable to relinquish my belief in a cause located in the *lower* strata of the atmosphere, it has been an exceedingly difficult thing to discover a substantial physical cause that will fix the exact location of a system of electric currents, or other source of these magnetic vectors, in this region, and, indeed, I had not been able to do so before arriving at the results of the kite observations as exhibited in the preceding papers of this series. We have been led, at length, very naturally to see in the movement of the positive (+) ions in streams, whose directions are determined by the temperature distributions in the lower strata, a sufficient cause for the diurnal variation of the electric potential field, and I shall now show that this cause also accounts equally well for the diurnal variation of the magnetic field in the North Temperate Zone.

The general relations may be represented schematically by fig. 57, "The probable relations between the temperature waves, the streams of positive (+) ions, and the magnetic vectors in the lower strata of the atmosphere". Let *A* represent the surface of the earth which is charged with negative electricity. A portion of this charge is derived from the ionized contents of the atmosphere, due to the action of the short waves of the solar radiation upon the constituents of the atmosphere, especially the aqueous vapor located within an arch spanning the Tropics. Another portion of the negative charge is probably derived from inside the earth, and is due to the excess of differential circulation of the negative (—) ions over the positive (+) ions in the atomic conflict at the prevailing high temperature and pressure, by which more of the negative electric ions are detached from the atoms and in circulating are polarized by the earth's rotation so as to produce the internal magnetism of the earth and an electrostatic charge at the surface. If the negative ions rotate more rapidly than the positive, as with the velocity of light, the deflecting force due to the earth's rotation must be large, and tend to cause these ions to move in planes perpendicular to the axis of rotation. This will cause an internal magnetic field directed from north to south.

The surface charge of negative ions is supposed to rest quite steadily on the earth, or within it, while the positive (+) ions of the atmosphere rise and fall from one stratum to another according to the change in the air temperatures, as if the positive (+) ions had an affinity for certain temperatures, which they seek through vertical and horizontal motions. Let *B* represent the ordinary surface temperature wave, with which it has never been possible to associate the diurnal magnetic vectors. Let *C* represent the semidiurnal temperature wave in the lower strata of the atmosphere as integrated in the diurnal convections, generally within half a mile of the ground. The maximum temperature occurs at 3 a. m. and 3 p. m., and the minimum at 8 a. m. and 8 p. m., both of these subject to the annual variation in time already indicated. Let *D* represent the probable streams of positive ions, directed vertically upward at 3 a. m. and 3 p. m., but downward at 8 a. m. and 8 p. m. It should be observed that at 3 a. m. the vertical upward current of the semidiurnal wave is really neutralized by the downward current of the surface wave, and that during the night hours we should have small residual motions on the whole of a downward direction; that, at 8 a. m. and 8 p. m. the downward semidiurnal waves prevail because the surface temperatures are nearly normal to the day and the convectional currents are producing lower temperatures; and, that, at 3 p. m. both the diurnal and the semidiurnal waves unite in a common upward vertical component. We may assume, then, that the positive ions descend vertically at 8 a. m. and 8 p. m., but ascend vertically at 3 p. m. The accompanying adjacent streams on the preceding side of the 8 a. m. vertical, bend to the left in the early morning hours, but to the right after that hour. These latter naturally recurve, becoming horizontal at 10 a. m. to 11 a. m. in order to ascend in the warm midday current. At 8 p. m. the positive (+) ions first descend, recurve by becoming horizontal at 6 p. m. to 7 p. m. and ascend in the warm afternoon current, while those farther to the right slowly descend throughout the night. Let *E* represent the corresponding magnetic deflecting forces, which are generally found to be at right-angles to the electric streams as thus located and always directed in the same sense.



This remarkably consistent corelation of cause and effect throughout the diurnal fields is greatly in favor of the theory here ascribed. Finally, it should be remembered that this entire temperature system is moving as indicated by the arrow *F* on the diagram from right to left, and that the warm wave is continuously intruding upon the cool regions to the left of it. If the positive (+) ions seek to avoid an excess of warm temperature by streaming from low levels during the hours from 10–11 a. m. to 6–7 p. m. into the higher levels with a maximum at 3 p. m., that is generally by moving upward in the warm current, the effect is to leave the positive (+) ions in the higher strata throughout the evening and night hours. There is not so much a continuous electric circuit, with the same velocity in all parts of it as in a conductor, but rather an alternate rise and fall of the electric charges at different parts of the day, that is a falling by night and a rising by day, somewhat as is indicated in the diagrams. The westward lateral movement of the diurnal system probably tends to keep

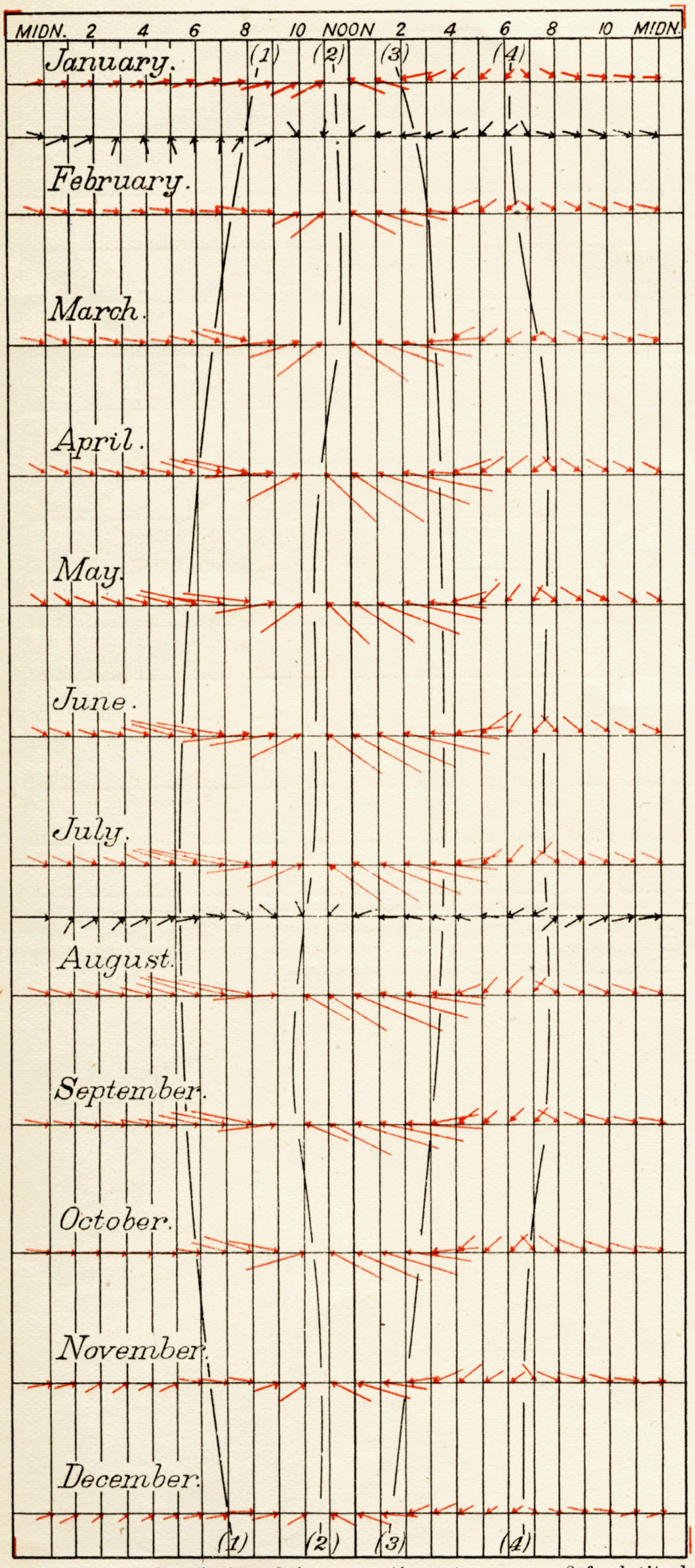


Fig. 55.—Diurnal variation of the magnetic vectors. s, a, β, for latitudes $+ 30°$ to $+ 60°$; s, a, for each month, β, for January and July.

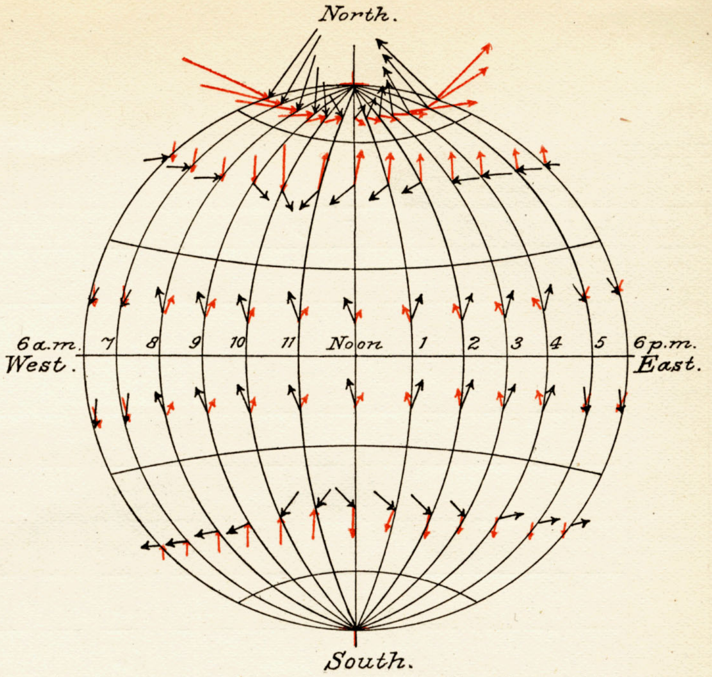


Fig. 58.—The streams of + ions causing the diurnal magnetic vectors in the Polar, Temperate, and Tropical zones of the earth.

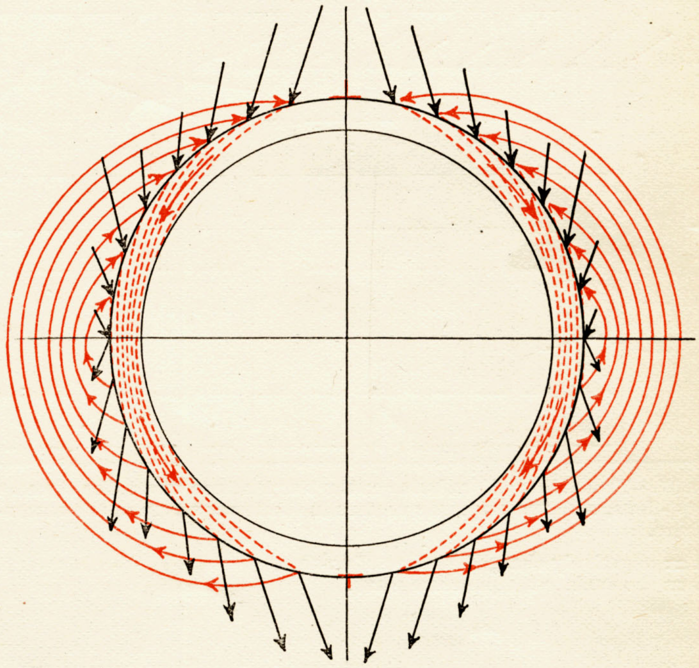


Fig. 59,—The general disturbance: Magnetic vectors directed southward and caused by a flow of + ions from south to north in the air.

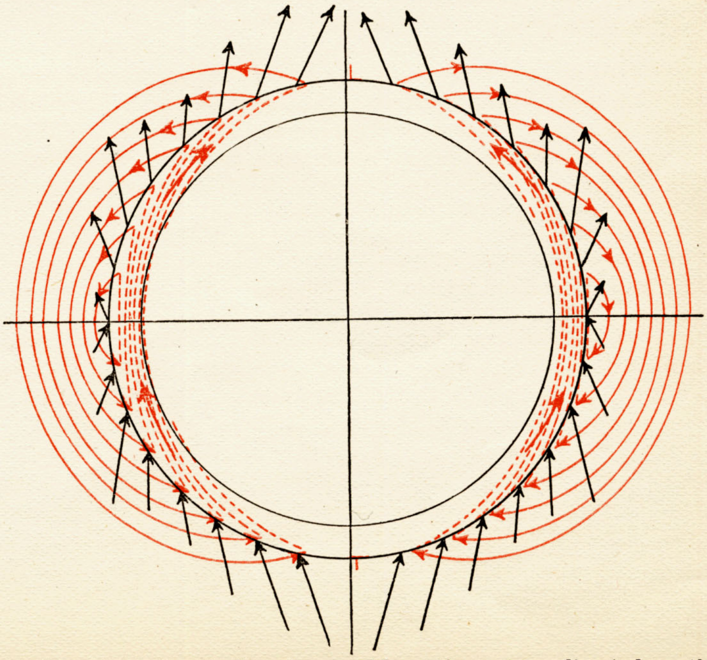


Fig. 60.—The general disturbance: Magnetic vectors directed northward and caused by a flow of + ions from north to south in the air.

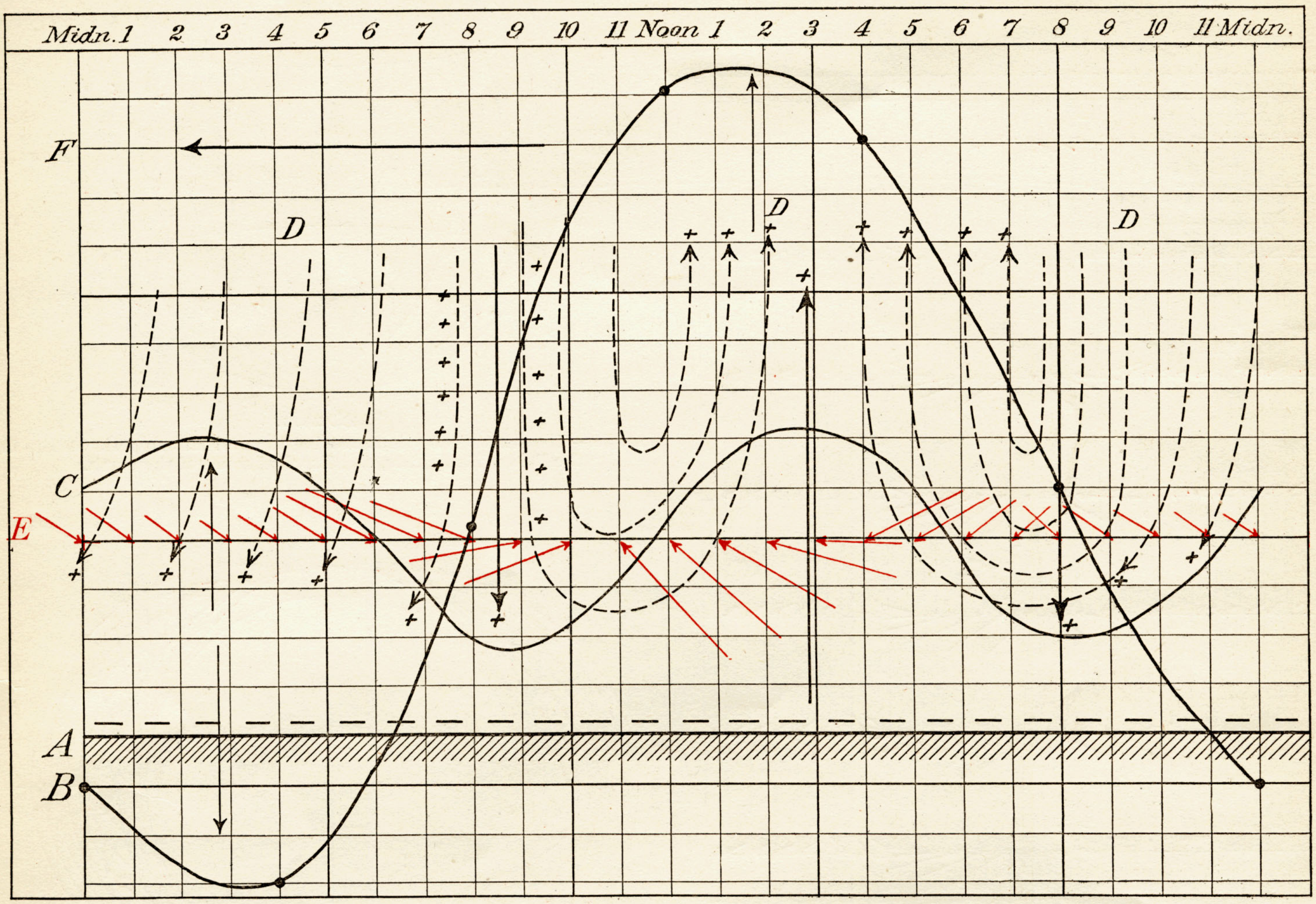


Fig. 57.—Probable relations between the temperature waves, the streams of + ions, and the magnetic vectors in the lower strata of the atmosphere.

A = negatively charged surface of earth.
B = the surface temperature wave.
C = the semidiurnal temperature wave at the height of 400–600 meters.
D = the probable stream lines of the positive ions, as moving charges.
E = the corresponding magnetic vectors.
F = direction of motion of the system.

wider open the streams of ions before noon, at 10 a. m. to 1 p. m., and to make them closer together at about 6 p. m. to 7 p. m. At the same time, as already explained, there is produced the increase of the atmospheric electric potential gradient to a maximum at 8 a. m. and 8 p. m. by the approach of the positive (+) ions to the negative (—) ions lying at the surface, also, an increase in the rate of dissipation of the two kinds of charges by the more immediate mixture and contact. It is not necessary to remark that we do not suppose that the positive (+) ions and the negative (—) ions are separated from each other so exclusively as is here indicated, but only that there is an excess of the positive (+) ions in the strata above the ground, and an excess of the negative (—) ions near the surface. It may be noted that the conflict in direction from 4 p. m. to 9 p. m. between the convection air currents and between the streams of the ions, one being upward and the other downward, is very favorable to the production of thunderstorms.

THE DIURNAL MAGNETIC VECTORS IN THE POLAR, TEMPERATE, AND TROPICAL ZONES OF THE EARTH.

Similar considerations applied to the magnetic hourly vectors which have been computed in the other zones of the earth, and described in chapter 4 of Bulletin No. 21, lead to the following conclusions, illustrated schematically in fig. 58. The normal magnetic field of the earth, positive in the Southern Hemisphere, has the horizontal component directed northward, while the vertical is upward in the Southern Hemisphere, but downward in the Northern Hemisphere. The downward positive (+) ion stream repels the north end of the magnet eastward in the North Temperate Zone, but westward in the South Temperate Zone; the upward positive (+) ion stream works in the opposite sense. Hence, the descending positive (+) ion stream from 7 p. m. to 11 a. m. (fig. 57) in the Northern Hemisphere directs the north end of the needle eastward, but in the Southern Hemisphere, westward. The ascending stream directs it westward in the Northern Hemisphere and eastward in the Southern Hemisphere. The same diurnal temperature waves, therefore, produce the required opposite magnetic effect in the respective hemispheres. In the Tropical Zone the vectors on the sunward side are directed northward for the ascending positive (+) ion streams, and southward in the night, 4 p. m. to 8 a. m. for the descending streams. In the Polar Zone the outspreading magnetic sheets on the morning side of the pole imply a descending stream of ions which is directed from left to right, or west to east; and on the afternoon side the ascending and concentrating magnetic vector sheets imply an outflowing system of positive (+) ions which ascend into regions about the surface. Generally, these magnetic vectors in the three zones require electric currents directed from west to east in the Polar Zone athwart the direction of the lines of the solar radiation; those in the Temperate Zones require lines nearly in planes from north to south, and also athwart the solar radiation field; finally those in the Tropics require positive (+) ion streams parallel to the direction of the same radiation. These three rectangular systems of electric currents evidently form those types of couples, exactly the counterparts of the three sets of magnetic couples which were described in the same chapter of Bulletin No. 21. For some reason the positive (+) ions seem to prefer to travel at right angles or else parallel to the lines of the electromagnetic radiation, even when they are passing along paths which are rendered favorable by the temperature conditions already existing in the lower strata of the atmosphere. It is evident that these prevailing conditions imply a possible solution of several important physical questions in electricity and magnetism in the earth's atmosphere, when suitable observations have been acquired. The theory which I advanced to account for the observed diurnal magnetic vectors in my preliminary papers is now much more satisfactorily stated, by such an addition to its terms as has been drawn from the process depending upon the ionization and temperature effects of the solar radiation in the lower atmosphere. Apart from clearness of exposition, it seems to me that the view there advanced, namely, that the magnetic vectors are products of the electromagnetic radiation as the result of its action on the atoms of the atmosphere is substantially strengthened. The entire subject, though intellectually more satisfactory, is also much more difficult to handle scientifically, because the intermediate steps involved in the action of the ions in relation to the temperature, must be worked out by observations in the lower strata of the atmosphere, and such data are very difficult to acquire in a reliable form.

THE SYSTEM OF DAILY MAGNETIC VECTORS, AS DISTINCT FROM THE HOURLY VECTORS.

Besides the system of hourly deflecting magnetic forces described in chapter 4, Bulletin No. 21, I also worked out a second vector system, which gives the vectors day by day, disturbing the normal magnetic field in the day intervals, taking the several successive groups of 24 hours in succession. These vectors are summarized in chapter 3, of the same bulletin, and it was there shown that they consist of vectors acting nearly in the planes of the magnetic meridians directed northward or southward as the case may be. Since the entire magnetic field of the earth is involved in these disturbances, which often run three or four days in the same direction, before reversal to the other side of the normal occurs, it is necessary to seek for a general cause instead of one that is distinctly local. The mere temperature effects of meteorological circulation can not be the dominant cause, because the two systems of conditions do not synchronize. It was also shown that this general magnetic field, taking the annual values of the vector *s*, does vary in parallel with that of the solar field as shown by the frequent number of spots, faculæ, and prominences. According to that interpretation of several phenomena which was adopted and which is probably physically correct, the sun was found to be magnetized. The solar action and the magnetic terrestrial effect undoubtedly synchronize in the long run, but there has been great difficulty in assigning so large physical fluctuations to the sun itself as seem to be required to account for the observed magnetic conditions at the earth. It has seemed to me necessary to assign to the direct magnetic field of the sun at least the function of setting in operation such terrestrial forces in the earth's atmosphere as should make up between them the required magnetic efficiency. Just what that terrestrial process is in fact, there has been trouble in detecting, and in assigning to it a sufficiently natural *modus operandi*. The violent fluctuations of the magnetic field could hardly be ascribed exclusively to variations in the normal solar electromagnetic radiations, for two reasons: (1) The sun would be a variable star of such a convulsive type as to be inconsistent with the comparatively steady flow of heat which the earth receives from it. Nor can this view be suitably modified by adding such a bombardment of solar ions as Arrhenius has suggested, because their possible efficiency is not nearly great enough to match the great magnetic fluctuations which are continually being recorded. (2) The vector system pertaining to these daily disturbances is entirely different in type from that found in the hourly variations. Indeed, I showed by the computation on Table 15, page 76, Bulletin No. 21, that in the case of strong disturbances the ordinary hourly disturbing vectors (fig. 58) are transformed hour by hour into a system of vectors like the general type (fig. 59), thus proving that these two phenomena have essentially different originating causes, so far as their effects on the observed magnetic vectors are concerned. I have not failed to recognize the difficulties of my own theories in this problem, nor have I discovered in other papers a solution which seemed in anywise competent to account for all the conditions at the solar end and at the terrestrial end of the line of cause and effect. The following view is, therefore, suggested with the impression that it forms an excellent working hypothesis for further examination.

Taking such a group of lines of force as are to be found on charts 17, 18, of Bulletin No. 21, which shows that the magnetic force is subject to world-wide variations of the same type on the same dates, it is evident that the normal field of the entire earth is for a while disturbed by a set of vectors pointing southward, and again by a set of vectors pointing northward. The mean vectors of this system at the several latitudes of the earth were computed, and they are plotted on chart 10 of Bulletin No. 21. They have longer vectors in the polar regions and in latitudes 20° to 40° than in the latitudes 40° to 60° and 0° to 20°. I have transferred them to fig. 59, which shows the magnetic vectors s directed southward and to fig. 60, which shows them pointing northward, of course referring to two seperate occasions. This alternate action, or reversal of the entire system of magnetic deflecting forces, is the phenomenon to be explained.

By extending our notion of streams of positive (+) ions moving from point to point in the atmosphere, we have merely to suppose that on certain provocations the positive (+) ions move from one hemisphere to the other in the atmosphere, returning again through the outer shell of the earth, as indicated on the diagrams. For a southward directed magnetic system, the positive (+) ions stream from the Southern Hemisphere along the arches in the atmosphere most favorable to their movement, whether due to temperature and vapor conditions, or to special ionization and conductivity functions. This flow of the positive (+) ions induces the magnetic vectors at the surface, and the positive (+) ions stream back from the Northern Hemisphere to the Southern through the crust of the earth, thus causing the earth currents which always accompany agitation of the normal magnetic field. For a northward directed system of vectors the positive (+) ions stream from the Northern to the Southern Hemisphere in the air, and return thence through the outer shell of the earth. The magnitude of the disturbance of the normal magnetic field depends upon the intensity of the stream of ions flowing along these paths, and that is a function of the number of the ions and the velocity of their motion,

$$\lambda = e\,(n_+ v_+ + n_- v_-),$$

where e is the charge of electricity of each ion, n_+ and n_-, the number of the positive (+) ions and the negative (—) ions, and v_+ and v_-, the velocity of the same. The simultaneous occurrence of the aurora in both hemispheres is evidence of the action of the ions which, in traversing the gases of the atmosphere in the low or the high strata, produce the observed luminous effects as phosphorescence or fluorescence. It should be observed that the hourly location of the aurora frequency occurs in the regions marked out on fig. 58 by the streams of ions, that is in the early morning and the early evening hours, since there is a region of minimum of frequency stretching from 11 a. m. across the polar region to 11 p. m.

This simple explanation of the long series of interrelated phenomena, which has so long escaped a natural correlation, has much to commend it to careful consideration. The quantitative determination of the number of ions involved, and their velocity of motion in the circuit from one hemisphere to the other, will require much exact research work upon the various functions involved in the physical processes.

THE DISTRIBUTION OF THE APERIODIC DISTURBANCES.

It has been very difficult to assign to the observed disturbances of the magnetic field, that is to the large variations of a spasmodic character, like temporary storms, which occur in the normal field, a satisfactory explanation. The attempt to ascribe the physical cause exclusively to variations of the solar action *in situ*, that is in the sun itself, as for example, the sun spots, or the prominences, is attended with unusual troubles of a physical nature. The following analysis may tend to throw some light on the subject.

The disturbances which occurred at Washington, D. C., during the years 1889, 1890, and 1891 were subjected to an analysis similar to that used in other connections, by which the polar disturbance vectors σ, s, α, β, were computed for each half hour of those days on which the traces were decidedly agitated, as 1889, February 28, 29, March 5, 6, 17, and so on throughout the three years. The purpose was to fix their daily distribution as a diurnal period, and the direction from which they come upon the normal field. The mean vector for the 24 hours was,

s = 245	for β	between	315°	and	45°	that	is	north;
315	" β	"	45°	"	315°	"		west;
333	" β	"	135°	"	225°	"		south.
308	" β	"	225°	"	315°	"		east.

Hence, the south quadrant receives the strongest impulse, while the east and west quadrants are more disturbed than the north quadrant. Fig. 61 contains the curve of relative numbers showing the diurnal frequency of the disturbance, the maxima being at 12 to 1 p. m. and 12 to 1 a. m. Comparing with fig. 57, it is seen that these maxima agree with the position of the maxima of intensity of the ascending stream of positive (+) ions, as determined by the temperature curve of the lower strata, that is the one located a few hundred meters above the surface. We may infer that one source of the magnetic disturbances is in the temperature waves which induce the movement of the streams of positive (+) ions, especially in a vertical direction. Hence, these hourly magnetic disturbances are specifically meteorological phenomena occurring in the lower strata of the atmosphere, and are the products of the solar radiation produced through the intermediate agency of the ionization and temperature waves.

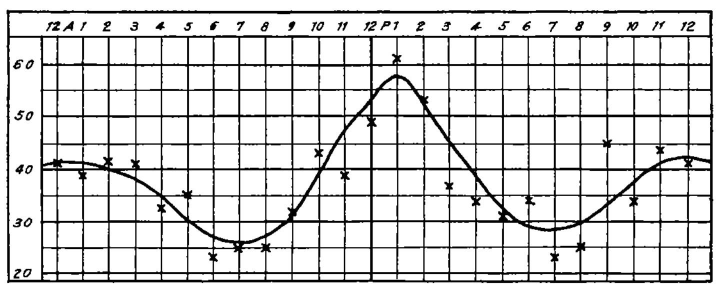


FIG. 61.—Distribution of the hourly magnetic disturbances at Washington, D. C., in the years 1889, 1890, 1891.

There is yet another cause for the other type of great magnetic storms which endure for several days, as distinct from those lasting a few hours, and cause the excessive variations in the diurnal field. In working up my data into the 26.68-day period, and deducing the resulting mean magnetic curve, as shown on chart 21, Bulletin No. 21, or by the upper curve on fig. 62, I excluded the large magnetic disturbances beyond a certain amplitude, for the sake of obtaining the normal structural magnetic impulse due to the rotation of the sun on its axis, if any such exists. The curve mentioned has been found to reappear generally, though at the expense of much waste of material in computing, to eliminate the other kinds of irregularities by mutual self destruction, in nearly all the solar and terrestrial phenomena. It, therefore, seems to point to an organized mass in the sun due to a highly viscous mass having great rigidity at immense pressure, or to a definite organic circulation. Similarly I have counted out the dates of occurrences of the magnetic disturbances recorded at Greenwich, 1882–1903, as collected by Mr. Maunder in his paper, Monthly Notices R. A. S., November, 1904, and entered them in a table based upon the 26.68-day ephemeris. The result is shown also in fig. 62, and it seems to imply that the 26.68-day period is at the basis of the distribution of the great magnetic storms, rather than the 27.35-day period, which is the average in the sun-spot belt.

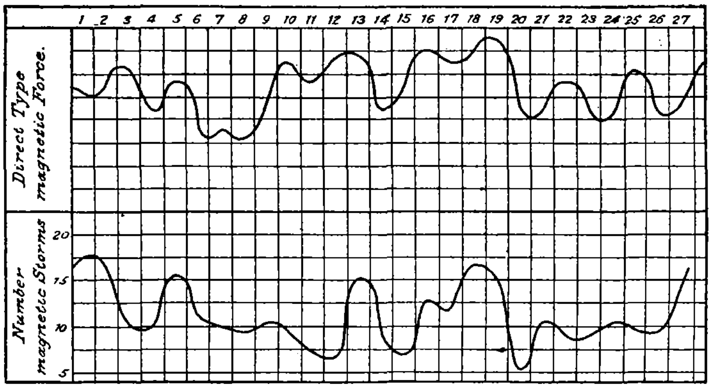


FIG. 62.—Distribution of the great magnetic disturbances in the 26.68-day period (Maunder's data).

In Terrestrial Magnetism, Vol. X, p. 12, March, 1905, Ch. Chree gives a table which shows the number of great magnetic storms, using Maunder's data, that commenced on the several hours of the day. These numbers are plotted on fig. 63 which shows that there is a distinct maximum at 1. p. m. The numbers are distributed without distinction as to hours during the night and early morning, but at 10 a. m. a pronounced increase in the number per hour set in which culminates at 1 p. m. and falls off gradually to 8 p. m. On comparing this curve, fig. 63, with that of the diurnal disturbance curve, fig. 61, it is seen that the principal maxima agree at the same hour. The inference is that the great disturbances lasting several days, as well as disturbances which are limited to a few hours in duration, each tend to concentrate about the 1 p. m. hour when the ascensional current of the positive (+) ions is strongest. From figs. 62 and 63 it is quite certain that the great disturbances have two terms entering into their composition, one belonging to the sun's atmosphere and the other to the earth's atmosphere. The final solution of this problem is evidently dependent upon a knowledge of many terms other than a mere enumeration and matching of the number of the sun spots and prominences with the magnetic traces.

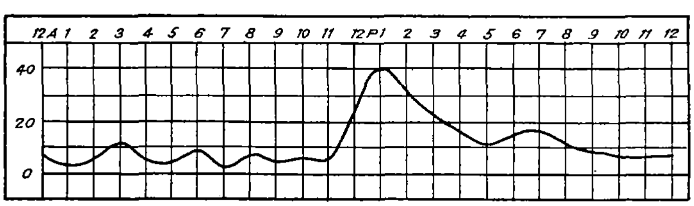


FIG. 63.—Number of great magnetic disturbances commencing at the several hours (C. Chree's Table, Terr. Mag. Vol. X, No. 1, p. 12).

The physical impulses from the sun to the earth may come in two ways, (1) by the radial path of the solar radiation, and (2) by the curved path of a direct magnetic polar field. Either of these may operate separately, or both of them may work together, to alter the normal balance among the positive (+) ions in the earth's atmosphere, and thus start them flowing in the paths indicated on figs. 58, 59, southward or northward as the case may be. As a matter of fact, the great magnetic storms lasting two or three days are found to require a deflecting vector system pointing southward, so that the positive (+) ions flow northward in the air strata. They may continue to flow as long as the solar impulse, whether of radiation or of direct magnetic field, is passing the position of the earth in its orbit. On this view the strain is removed from the original theory that the sun can not by direct action as a magnetic sphere influence the earth to the full extent required by the observations, because only a part of the energy traverses the cosmical space from the sun to the earth, while the remainder is simply due to the streams of ions in the atmosphere flowing as adjustment currents.

Enough has been shown, I believe, to make it clear, (1) that the variations of the terrestrial magnetic field are distinctly meteorological effects, and should properly be examined by the meteorologist rather than by the geophysicist; (2) that this interaction of the electric, magnetic, and temperature effects, whether at the sun or at the earth, constitutes one of the most fascinating problems open to scientific research. If the production of ions by solar action, their distribution statically and dynamically under the influence of atmospheric pressure, temperature, and vapor contents can be thoroughly worked out, the result will be to raise meteorology to a practical science of the highest rank. The numerous cross connections between radiation, whether variable or constant, the ionization in the solar and in the terrestrial envelopes, the consequent circulation of the solar mass and of the earth's atmosphere, the resulting weather and climates, make up a series of research problems of much difficulty, and yet of such promising value to all men as to justify a much greater activity on the part of astrophysicists and meteorologists than has been given to the subject of cosmical meteorology in the past.

THE COMPONENTS OF THE DIURNAL WIND VELOCITY.

In chapter 9, of the International Cloud Report, some account was given of the relation between the distribution of the pressure waves and the magnetic field vectors in the polar regions, as well as in the Tropics and middle latitudes. It was shown that the diurnal wave in the Tropics and the temperate zones advances over the earth as a long double wave extending from latitudes +60° to −60°, but that in the Polar Zone a single wave of maximum crosses the poles with a phase about 90° different from either of the maximum pressure waves in lower latitudes. It appears that the distribution of the magnetic vectors is closely associated with this single pressure wave in the Arctic regions, but I could give no suitable explanation of this sudden transition from the double to the single wave at the latitude 60°. It now appears that the semidiurnal waves are due to temperature effects and convection currents in the lower strata, as within 600 meters of the surface, and that above them from 600 meters to 3000 meters there exists a single temperature wave, located halfway between them, which likewise is produced as the result of the temperature distribution in the lower strata. Now, since in the temperate zones, the double temperature waves exist at low levels and the single temperature wave at high levels, it is quite likely that this single wave descends to the surface in the Polar Zone, and induces the single pressure wave which accompanies it. Thus, the single temperature and pressure waves rest on the surface in the polar zones, but pass overhead as an arch in the temperate and the tropical zones, higher in the Tropics than in the middle latitudes. This is quite similar to the distribution of the aqueous vapor contents in an arch, and it is probable that the positive (+) ions travel along this high pressure arch through the earth's atmosphere rather than by any other route. The vectors of figs. 59, 60 show that long vectors occur in the Polar Zone, and in the latitudes between the eastward drift of the temperate zones and the westward drift of the Tropics, that is to say, in the belts of the earth where the high pressure distributions come to the surface. The cloud belts of the Temperate Zone, latitudes 40° to 50°, and near the equator, +10° to −10°, apparently impede the circulation of the streams of ions and so produce short disturbing vectors in those belts.

Finally, by comparing the diurnal wind vectors, as deduced from the surface and the free air observations, it will be seen that they harmonize closely with the other results of this analysis. I may remark in conclusion, that there seems to be little need to adopt the theory of Arrhenius, that the magnetic disturbances are due to a bombardment of the solar ions traversing the space between the earth and the sun, because the disturbance of the normal temperature, or the normal electrical field and magnetic field by radiation effects, or by the direct magnetic effects, is sufficient to set up a counterbalancing circulation of the ions. The entire system of the sun and the earth constitute a delicately balanced wireless telegraphic system, and the ions may be regarded as sensitive coherers, which respond to every impulse tending to disturb the equilibrium. It should be especially observed that the variation of the magnetic field at the surface most effectively and simply integrates the entire efficient energy expended in these several types of force. If the temperature waves in the lower strata disturb the ions, and these induce the magnetic deflecting forces, then, in the inverse order, the magnetic force at the ground measures the nature of the temperature wave passing overhead. In this aspect of the case the magnet can be made to register the temperatures in the lower strata of the air at least indirectly, and probably very efficiently, when the function becomes fully understood, and in this sense a magnetic observatory is essential to the progress of the higher meteorology.

TABLE 10.—*Hourly values of the polar coordinates s, α, β at five stations in the North Temperate Zone.*

W. = Washington. P. = Paris. V. = Vienna. T. = Tiflis. Z. = Zi-ka-wei.

FEBRUARY.

Hours.	s W	s P	s V	s T	s Z	Means.	α W	α P	α V	α T	α Z	Means.	β W	β P	β V	β T	β Z	Means.
12 a	4	10	9	9	7	8	—28	— 5	—12	—12	— 8	—13	273	276	302	297	180	265
1...	3	5	8	10	6	6	—25	—10	— 7	—11	—13	—14	234	281	320	281	180	259
2...	2	3	13	7	7	6	—26	0	+ 4	—18	— 7	— 9	349	288	337	286	195	271
3...	1	4	8	3	7	5	—27	0	0	0	— 8	— 7	280	280	336	315	195	279
4...	2	3	9	3	5	4	—20	0	— 6	0	0	— 5	292	288	340	378	180	296
5...	4	3	16	5	6	7	—46	+17	— 7	+11	—18	— 9	309	315	352	360	190	305
6...	4	5	15	6	7	7	—23	+11	— 4	+ 9	— 8	— 3	309	323	348	398	180	312
7..	7	7	18	8	3	9	—21	+ 9	— 6	0	+ 9	— 2	313	333	347	253	162	282
8...	10	7	22	13	9	12	—10	+ 8	—10	0	— 6	— 4	301	326	329	322	206	297
9...	11	6	20	14	9	12	— 4	+ 9	— 4	+12	0	— 3	289	279	290	294	308	292
10...	10	7	20	10	13	12	+ 8	+27	+10	+37	+18	+20	271	211	236	263	305	257
11...	8	11	34	10	12	15	+23	+34	+25	+61	+28	+34	228	144	200	142	333	209
12 p	12	16	40	16	15	20	+22	+23	+22	+40	+23	+26	153	106	160	100	8	105
1...	16	19	31	18	19	21	+13	+15	+16	+27	+19	+18	128	93	145	90	27	97
2...	16	15	31	16	16	19	+13	+12	+13	+11	+ 7	+11	100	94	124	94	33	89
3...	16	10	24	14	12	15	+ 9	0	— 3	— 4	+ 5	+ 1	87	96	111	116	34	89
4...	10	7	15	11	7	10	+12	—16	—16	—15	—45	—16	81	117	102	128	36	93
5...	6	4	10	10	5	7	+23	—35	—29	—23	—90	—31	86	90	122	129	0	85
6...	6	4	6	9	6	6	+18	—57	—45	—36	—45	—33	91	90	75	164	180	120
7...	3	3	4	7	5	4	+23	—45	—65	—45	—22	—31	245	295	65	217	180	200
8...	2	5	6	8	10	6	—23	—21	—45	—45	0	—27	279	215	333	210	191	265
9...	4	6	10	8	9	7	—26	—18	—29	—30	— 6	—22	256	288	306	254	167	257
10...	6	7	12	8	7	8	—25	— 8	—20	—40	— 8	—20	271	286	304	260	172	263
11...	6	8	13	8	3	8	—31	— 7	—13	—30	—18	—20	286	278	303	270	163	260
12...	4	10	9	9	7	8	—28	— 5	—12	—12	— 8	—13	272	276	302	297	180	265

AUGUST.

Hours.	s W	s P	s V	s T	s Z	Means.	α W	α P	α V	α T	α Z	Means.	β W	β P	β V	β T	β Z	Means.
12 a	5	10	13	9	3	8	—10	—17	—13	—21	—18	—16	360	315	328	320	135	292
1...	7	9	10	10	2	8	+ 5	—13	—17	—17	—26	—14	445	319	315	307	360	329
2...	6	8	9	9	7	8	+ 8	—15	—18	—13	—26	—13	341	320	297	306	342	321
3...	5	9	13	10	11	10	+12	— 6	—12	—17	—33	—11	352	305	300	294	325	315
4...	8	10	13	11	14	11	+19	—11	—18	—22	—30	—12	292	286	297	294	331	300
5...	10	12	18	16	20	15	— 2	—14	—20	—22	—33	—18	303	279	298	287	320	297
6...	21	16	18	23	40	24	— 8	—15	—22	—18	—25	—18	285	266	280	270	297	280
7. .	31	21	20	32	49	31	— 1	—11	—20	—16	—16	—13	272	252	279	254	278	267
8...	36	23	22	35	46	32	— 1	— 4	—21	— 9	—10	— 9	151	232	236	240	271	226
9...	34	22	23	31	25	27	+ 6	+14	— 9	+ 5	—21	— 1	225	218	209	217	265	227
10...	25	20	28	21	12	21	+18	+30	+15	+23	+58	+29	183	174	177	186	90	162
11...	22	26	35	22	31	27	+22	+35	+31	+40	+26	+31	155	133	157	114	80	128
12 p	32	35	40	35	43	37	+13	+30	+32	+27	+15	+23	112	96	118	87	78	98
1...	32	34	37	40	43	37	+11	+20	+25	+17	+ 8	+16	93	97	101	77	72	88
2...	29	30	30	37	32	32	+ 4	+10	+15	+14	+ 4	+ 9	81	97	84	71	67	80
3...	21	20	21	27	27	21	— 5	— 6	+13	+ 8	— 3	+ 2	71	86	81	72	65	75
4...	13	13	12	15	3	11	—29	—33	—14	0	—18	—19	51	80	85	74	90	76
5...	9	9	4	6	16	9	—43	—72	—63	—39	—15	—46	38	45	90	90	165	86
6...	7	10	4	4	23	10	—46	—72	—45	—75	—16	—51	14	315	315	180	190	63
7...	5	10	9	4	22	10	—40	—45	—20	—58	—15	—36	350	343	346	90	177	45
8...	6	11	12	5	15	10	—21	—33	—20	—63	+ 3	—27	348	334	350	360	176	314
9...	5	10	14	6	9	9	—26	—29	—17	—45	0	—23	345	319	346	329	262	320
10...	6	11	12	6	11	9	—31	—22	—20	—31	—10	—23	340	315	338	322	165	296
11...	7	9	14	7	11	10	—17	—20	—17	—27	—20	—20	348	315	333	308	165	274
12...	5	10	13	9	3	8	—10	—17	—13	—21	—18	—16	360	315	328	320	135	292

TABLE 11.—*Vectors of the diurnal magnetic deflecting forces.*

β azimuth angle, N. = 0°, W. = 90°, S. = 180°, E. = 270.
s in terms of 0.00001 C. G. S. unit.
α vertical angle, positive to zenith.

Hours.	January. s	α	β	February. s	α	β	March. s	α	β	April. s	α	β
		°			°			°			°	
12 a....	6	+ 3	258	8	—13	265	9	—11	285	7	—30	290
1......	4	+16	388	6	—14	259	8	—19	288	8	—22	295
2......	4	+19	296	6	— 9	271	8	—14	291	8	—18	294
3......	4	+23	343	5	— 7	279	8	—10	304	9	—12	288
4......	5	+14	363	4	— 5	296	8	— 9	298	9	—14	286
5......	6	+10	373	7	— 9	305	7	— 9	331	10	—14	285
6......	7	+10	365	7	— 3	312	10	—11	339	14	—19	289
7......	10	+ 6	354	9	— 2	282	12	—21	311	21	—15	234
8......	10	+ 3	321	12	— 4	297	17	—17	278	27	—11	259
9......	12	+10	298	12	— 4	292	21	— 2	266	26	+ 1	241
10......	11	+21	217	12	— 3	257	20	+14	240	23	+26	221
11......	13	+24	176	15	+20	209	22	+35	182	26	+44	161
12 p....	16	+20	120	20	+34	105	27	+34	103	35	+34	94
1......	17	+ 9	101	21	+26	97	29	+20	95	40	+19	84
2......	13	— 7	98	19	+18	89	29	+12	89	36	+12	81
3......	8	—21	99	15	+11	89	21	— 2	86	25	— 1	78
4......	6	—36	115	10	+ 1	93	12	—14	94	16	—16	84
5......	5	—37	131	7	—16	85	8	—31	134	11	—33	100
6......	5	—40	120	6	—31	120	6	—28	122	11	—37	140
7......	5	—47	207	4	—33	200	6	—31	123	9	—37	131
8......	6	—30	264	6	—31	265	7	—29	214	11	—30	285
9......	7	—14	260	7	—27	254	8	—28	276	9	—34	289
10......	7	— 9	256	8	—22	263	9	—19	269	9	—29	284
11......	7	— 7	256	8	—20	260	9	—18	276	8	—26	283
12......	6	— 3	258	8	—20	265	9	—11	285	7	—30	290

Hours.	May. s	α	β	June. s	α	β	July. s	α	β	August. s	α	β
		°			°			°			°	
12 a....	6	—31	278	7	—24	278	8	—25	272	8	—16	292
1	7	—36	281	8	—20	281	7	—28	335	8	—14	329
2......	7	—20	302	7	—15	282	8	—22	302	8	—13	321
3......	7	—19	302	8	—10	291	9	—18	317	10	—11	315
4......	9	—17	296	10	—12	288	9	—25	295	11	—12	300
5......	14	—16	284	16	—14	286	16	—20	290	15	—19	297
6......	22	—13	276	25	—11	275	23	—14	279	24	—18	280
7......	26	— 9	263	30	— 5	265	29	—10	265	31	—13	267
8......	28	— 4	256	30	0	252	31	— 6	251	32	— 9	226
9......	23	+ 7	235	26	+ 7	235	27	+ 5	233	27	— 1	227
10......	19	+34	198	22	+29	208	24	+20	208	21	+29	162
11......	24	+44	106	25	+36	139	25	+35	139	27	+31	128
12 p....	30	+33	97	31	+30	100	29	+30	105	37	+23	98
1......	35	+21	81	35	+23	81	34	+21	89	37	+16	88
2......	32	+13	73	34	+14	83	32	+14	83	32	+ 9	80
3......	23	+ 2	78	28	+ 1	81	26	+ 4	81	21	+ 2	75
4......	14	—15	81	19	—12	80	17	—10	78	11	—19	76
5......	10	—45	94	14	—36	87	10	—32	87	9	—46	86
6......	9	—51	112	9	—53	76	9	—50	111	10	—51	63
7......	8	—48	166	9	—49	148	10	—38	96	10	—36	45
8......	8	—34	256	10	—46	320	9	—33	312	10	—27	314
9......	9	—31	294	9	—38	310	9	—30	299	9	—23	320
10......	8	—27	277	8	—33	304	9	—22	292	9	—23	296
11......	7	—28	282	8	—27	287	8	—27	277	10	—20	274
12......	6	—31	278	7	—24	278	8	—25	272	8	—16	292

Hours.	September. s	α	β	October. s	α	β	November. s	α	β	December. s	α	β
		°			°			°			°	
12 a....	9	—11	323	10	—10	272	9	+ 2	268	6	+10	252
1......	8	— 9	333	8	0	306	7	+ 6	225	7	+16	256
2......	10	— 6	322	7	+ 2	319	6	+23	286	3	+26	277
3......	10	— 7	317	8	— 1	313	5	+23	322	3	+28	316
4	12	— 9	320	8	+ 1	333	6	+16	331	4	+14	362
5	13	—10	311	9	0	344	7	+17	365	6	+10	364
6	16	—12	300	10	— 7	341	10	— 4	347	7	+ 3	369
7......	22	—12	274	14	—16	310	10	— 6	353	9	+ 4	359
8	25	— 8	252	20	—15	274	10	—12	319	11	— 3	349
9......	25	+ 2	226	22	— 9	247	10	+14	281	9	+ 8	311
10......	21	+20	178	24	+15	214	12	+30	214	7	+22	238
11......	29	+27	135	24	+26	163	18	+25	174	11	+27	175
12 p....	35	+17	111	29	+24	107	22	+18	96	14	+18	121
1......	34	+13	92	32	+16	98	19	+10	94	14	0	111
12......	30	+ 1	82	26	+ 9	89	15	— 6	99	11	— 1	109
3......	18	—10	77	18	— 6	87	13	—20	115	8	—18	108
4......	10	—34	89	9	—34	110	11	—35	116	8	—20	133
5......	7	—41	159	8	—36	130	9	—30	142	6	—24	126
6......	7	—50	148	9	—42	156	8	—35	116	4	—24	128
7......	7	—43	168	8	—51	285	7	—36	195	4	—27	227
8......	9	—32	282	9	—36	272	9	—22	256	5	—19	243
9......	8	—26	286	11	—23	272	11	—19	259	6	—15	250
0......	9	—18	290	11	—20	278	11	—18	265	7	—10	248
1......	8	—13	308	11	—15	289	9	— 6	264	7	+ 8	254
2......	9	—11	323	10	—10	272	9	+ 2	268	6	+10	252